IAP12 Rec'd PCT/PTO 31 JAN 2006

DISCHARGE RATE AND PRESSURE CONTROL SOLENOID VALVE

The present invention relates to a discharge rate and pressure control solenoid valve which may be used in a circuit including a low pressure part and a high pressure part.

Conventionally it allows the low pressure fluid rate to be controlled by means of a sliding spool in a liner in which at least one fluid feeding orifice and one fluid exhaust orifice are provided respectively, said spool being electrically actuated by means of an electromagnet acting in an opposite direction to recoil means. These recoil means are dimensioned and positioned so that, for a zero electromagnet control current, the passage between the feeding and exhaust orifices is closed, and then gradually opened according to a threshold value of the current.

Pressure control, also performed by the solenoid valve is applied to the high pressure fluid. This invention for example is applied to a gasoline injection system for a heat engine with a common rail. This system moreover forms another aspect of the invention. In this application, the usefulness of parallel discharge rate and pressure control results from the selective requirement of rapidly discharging said rail in pressure, for example when the user of the vehicle releases the accelerator.

The combination of pressure discharge in the case of overpressure in the rail and checking the discharge rate control has never been applied to this day in a same device.

In the example above, the rail is fed with high pressure gasoline by a pump, itself dependent on low pressure gasoline from the tank via the solenoid valve of the invention, which controls the discharge rate thereof. Pressure control is performed on highly pressurized gasoline, downstream from the pump, and it is managed by a computer obtaining information on the value of said pressure via a sensor positioned in the common rail.

In the text which follows, in order to explain the operation of the solenoid valve of the invention, reference will systematically be made to the example of engines with a common rail. The low pressure with a discharge rate controlled by the solenoid valve is of the order of 6 bars at the inlet of the solenoid valve, from the gasoline tank and of 5 bars at the outlet,

upstream from the pump. The latter raises it to 120 bars or to 200 bars according to the pump models and the actuation operations. Therefore, pressures of these orders of magnitude are the ones that the solenoid valve should handle when it applies high pressure control.

The pressure in the rail is controlled by the control of the valve discharge rate. The pressure sensor provides information which allows the computer to transmit a set value to the valve, requesting it to provide more or less discharge rate. Therefore, this is a closed loop operation. If the pressure is too high in the rail, the information provided by the sensor will tell the calculator to send to the solenoid valve a set value requesting it to act on the high pressure in order to reduce it.

For this purpose, and according to the invention, the recoil means against which the electromagnet acts are inserted between the spool and a flap device capable of closing an inlet orifice in the high pressure fluid liner, which communicates with the low pressure fluid feeding orifice at least in the position of the spool corresponding to a control current less than the threshold value allowing the passage between the low pressure fluid feeding and exhaust orifices to be opened. These recoil means are further positioned and dimensioned so that the flap may be opened for a current equal to or near zero, in order to cause the pressure in the high pressure circuit to drop.

In other words, when the pressure value is too high in the rail, the computer will be instructed to reduce the current sent to the electromagnet, and therefore reduce the force exerted on the internal spring by the mobile core of said electromagnet. The overpressure may then open the flap and discharge the rail, with a small discharge rate, in order to cause the pressure to drop therein. Theoretically, this discharge rate is sent to the gasoline tank.

Conversely, if the pressure in the rail is too low, the set current value sent by the computer for the benefit of the electromagnet is increased, and the consequence is an increase in the discharge rate, and therefore of pressure in the rail. In this case, the recoil means exert a larger pressure on the flap, which cannot open and maintains the high pressure in the rail.

Preferably, the mobile spool is positioned and dimensioned so that the low pressure fluid feeding and exhaust orifices are not connected until the force exerted by the spool on the flap device via the recoil means, in order to

close said flap, is sufficient for providing said closure when the pressure reached in the high pressure circuit is the rated operating pressure.

In other words, the different components involved in controlling the discharge rate on the one hand and the pressure on the other hand, for both low and high pressure circuits respectively, should be configured in such a way that control of the low pressure rate by connecting the feeding and exhaust orifices is only performed after reaching a rated and stable pressure in the high pressure circuit, for current values which guarantee that the flap cannot open. With this separation of the control features, the idle speed of the engine may be controlled very accurately and with constant pressure.

In reality, leaks occur between the low pressure feeding and exhaust orifices, even before the spool is in a position allowing a passage between them. The leakage rate is then raised to a high pressure by the pump, and used for having the engine run at idle, which does not require proportionality of the discharge rate relatively to the current. At this point, it is simply necessary that the current be set sufficiently high in order to prevent opening of the flap when the pressure in the rail allows the injectors to idle.

But there remains an interval between the current required for closing the flap at these pressures and the one required for operating the discharge rate control proportionally to the current, when the inlet and exhaust orifices are connected. The purpose and the effect of this interval is not to introduce pressure variations into the rail, which may vary the engine speed and therefore generate noise or cause operating problems at normal speed.

Preferably, the spool is driven by a pusher firmly attached to the mobile core of the electromagnet, the recoil means consisting of a coil spring axially positioned between the end of the spool and the flap device.

The general configuration is therefore axial, and successively comprises the mobile core of the electromagnet, a pusher rod, the spool, the coil spring, and the flap device.

According to one possibility, the flap device includes a sliding sleeve in the liner and actuated by recoil means having an axial arm provided with an end with a hemispherical aspect which may close the fluid inlet orifice, said orifice opening into the volume of the spool, at a seat against which the hemispherical end is pressed, in the event of closure of the flap.

According to one alternative, the flap device includes a ball which may close the high pressure fluid inlet orifice.

The aforementioned configuration is optimized so that the flap cannot randomly leak, because the program of the computer can only check for a constant leak, by the presence of the pressure sensor which provides closed loop operation. A random leak is banned, insofar that it may generate unacceptable pressure changes in the rail.

Whatever the operating mode of the flap, either with a ball or a hemispherical head arm, the configuration of the seat of this ball as well as the relative layout and shape of the different components, notably provided according to the value of the current, guarantee the absence of any hazards. In particular, the electromagnet is calculated so as to have constant force over the whole stroke of the spool, in order to improve positioning accuracy of the spool according to the set current value.

The seat for example consists in an axial conduit opening into the spool and chamfered at its link with the inlet orifice, said conduit being flanked with clearance spaces for the fluid, open onto the volume of the liner and obtained by a cylindrical milling cutter stroke with smaller thickness and with an axis perpendicular to that of the conduit, respectively.

The positioning of the ball or the arm is thus well guaranteed, as well as the guiding of the high pressure fluid from the circuit positioned downstream from the pump.

In the ball configuration, the liner includes a central axial protrusion provided so as to be inserted in the conduit of the seat and to exert a force on the ball.

In the hemispherical head axial arm configuration, it is the arm which is provided in order to be inserted in said conduit and to close the inlet orifice.

Preferably, the sleeve has at least one channel for letting the fluid pass through towards the spool.

Still preferably, the inlet orifice is provided in a part closing the liner, and its position is adjustable relatively to the latter. It is therefore possible to proceed with adjusting the position of the seat in order to optimize the operation of the valve.

According to the invention, for an electromagnet control current equal to zero, the recoil means exert on the flap a force such that the fluid is required to have a pressure of the order of 30 bars in order to open it.

As a rule, in the event of overpressure in the rail, the set current value sent by the computer to the electromagnet is either a zero value, or a value near zero. Considering the order of magnitude of the rated pressures which should prevail in the rail during running of the engine (120, 200 bars), there is no problem in opening the flap in the case of overpressure.

The invention, as already mentioned, also relates to a gasoline injection system for heat engines with common rails, provided with a solenoid valve as described above, the inlet orifice of which is connected to the high pressure fluid circuit positioned downstream from the pump.

In order that operation may be performed properly, the common rail includes a pressure sensor connected to an electronic central unit used as a computer and which provides the set current value to the electromagnet of the solenoid valve. The invention will now be described in more detail, with reference to the appended figures wherein:

- Fig. 1 shows a schematic illustration of the gasoline injection system according to the invention;
- Fig. 2 illustrates, as a sectional view, a solenoid valve with flap and ball according to the invention;
- Fig. 3 is a sectional view of a sleeve of the ball flap device;
- Fig. 4 is still a sectional view of the part including the seat of the ball of the flap device;
- Fig. 5 illustrates ideal pressure and discharge rate characteristics of the solenoid valve of the invention, and
- Fig. 6 illustrates these same characteristics in a plot more practically reflecting operation of the solenoid valve of the invention.

With reference to Fig. 1, the solenoid valve (1) of the invention is positioned between the gasoline tank (2) of the vehicle and a high pressure pump (3) for supplying gasoline to the common rail (4). The latter feeds injectors (5) providing gasoline to the cylinders of the motor. The rail (4) is moreover provided with a pressure sensor (6) connected to an electronic

central unit (7) which notably provides a set current value to the electromagnet of the solenoid valve (1). Therefore operation is performed in a closed loop. The flap (8) controls a loop connecting the high pressure part of the circuit (downstream from the pump (3)) and the low pressure part of the circuit (upstream from said pump (3)). In fact this loop returns to the outlet of the pump at the inlet of the solenoid valve (1) downstream from the fuel tank (2).

When overpressure is detected in the rail (4) by the pressure sensor (6), the electronic unit (7) sends a zero or low set current value so that the flap (8) may open under the effect of said overpressure. Gasoline is then sent back to the tank (2). The discharge rate control valve (1) and the flap (8) are in fact joined together in a single entity (E), which forms the discharge rate and pressure control solenoid valve according to the invention.

It is illustrated in more detail in Fig. 2, and consists of an electrical sub-assembly which tops a hydraulic sub-assembly. Conventionally, electrical functionalities are provided by an electromagnet which does not in the least need to be described in detail, within the scope of the invention, as it is known *per se*. It is sufficient to know that it consists of a coil (9) notably integrated into a magnetic armature (10) surrounding a mobile core (11), which drives a pusher (12) notably guided by a low polar part (13) the upper part of which is designed so that by varying the gap which it forms with the mobile core (11), it is possible to generate an electromagnetic force as constant as possible over the stroke of the core (11). A bearing (14) improves the guiding and sliding of the pusher (12). The electromagnet is overmolded in an envelope (15) integrating an external connector (16) containing connection terminals (17), in order to connect it for example to the electronic central unit.

The pusher (12) acts on a slidably mobile spool (18) provided with a peripheral recess (19) provided for connecting a feeding orifice (20) and an exhaust orifice (21) provided in the liner (22) of the hydraulic sub-assembly. These orifices (20) and (21) are connected via conduits (23, 24) of a frame (25) to the low pressure circuit. More specifically, the conduit (23) and the feeding orifice (20) are connected to the fuel tank, whereas the exhaust orifice (21) and conduit (24) are connected to the high pressure pump (3).

A coil spring (26) is positioned in the axis of the spool (18). One of its ends is fixed in an axial housing of said spool (18), whereas its other end actuates a sleeve (27) forming part of the flap device, which also comprises a ball (28). The sleeve (27) slides in the central bore of the liner (22), like the spool (18). The ball (28) rests on a seat (37) made in one piece (29) achieving the link with the high pressure circuit.

Thus, this part (29) includes an inlet orifice (30) immediately located under the seat (37) of the bore (28) and extended by a conduit (31) carrying the high pressure fluid. The sleeve (27) of the flap device as well as the part (29) is shown in more detail in Figs. 3 and 4, respectively. The sleeve (27) includes, in its face opposite the spool (18), a cylindrical housing (32) able to receive one of the ends of the spring (26). The diameter of this housing gradually narrows inwards, in order to fix the end of the spring (26). In the extension of the housing (32), channels (34 and 34') allow the fluid to pass through the sleeve (27). These channels, at least two in number, surround a cylindrical protrusion (35), the diameter of which is calculated for insertion into a conduit (36) of the part (29), in order to maintain pressure on the ball when it rests against its seat (37) (cf. Fig. 4). Routes (38 and 38') for discharging the fluid are positioned on either side of the conduit (36) and of the seat (37), made by means of a cylindrical milling cutter with a thickness less than that of the conduit (36). With the threading (39), it is possible to adjust the position of the part (29) to refine the operation of the flap device.

The seal of the different components is provided by O-rings distributed all around the liner (22). Operation of the assembly is more easily explained with reference to the diagrams of Figs. 5 and 6. In particular, its theoretical operation appears in Fig. 5. When the current is equal to zero, the force exerted by the spring (26) on the flap device and notably on the ball (28) allows pressure of the order of 20-30 bars to be contained in the rail (4). For a higher pressure, the flap opens and overpressure is discharged into the liner (22), towards the orifice (20) and the conduit (23). The discharge rate curve (C_2) actually shows that for this current value, there is theoretically no discharge rate between the feeding orifice (20) and the exhaust orifice (21). Taking into account the location of the peripheral recess (19), this lack of discharge rate is extended up to a value of about one ampere, following

which the discharge rate increases linearly. Now, between zero and one ampere, and as the electromagnet control current intensity increases, the force exerted via the spring (26) on the flap device and consequently on the bore (28) also increases so that it may contain an increasingly large pressure in the high pressure part of the circuit (curve C_1). Within the scope of the invention, it is required that the rated operating pressure (120 bars on the figure) be reached for a current value less than the threshold value from which the discharge rate increases linearly (one ampere on curve C_2). With this condition, it is possible to control the idle discharge rate very accurately and with constant pressure.

In reality, the discharge rate curve (C_2) rather has the aspect which appears in Fig. 6. Before obtaining the intensity threshold, there are leaks, directly connecting the inlet orifice (20) and the exhaust orifice (21) via the recess (19). These leaks, provided that they are under control, are not really a major drawback of the invention. However they should be less than the gasoline discharge rate required for having the engine idle. Knowing that the injectors operate from a pressure in the rail equivalent to about 70 bars, it is required that for this value, the leakage rate D_1 corresponding to a set current value I_1, be less than the gasoline flow rate required for idling.

With the assumption of an engine operating with a rated pressure of 120 bars in the rail, it is then required that this pressure be contained by the flap device for a current value I_2, corresponding to a leakage rate D_2 at the spool less than the threshold value I_s from which the leak is established between the feeding (20) and exhaust (21) orifices.

In actual operation, the leakage rate is therefore non zero when the current is equal to zero ($I=0$), and it increases when I increases.

Once again, it is preferable that the value I_2 be less than and clearly separated from the I_s value so as not to introduce pressure variations in the rail which may vary the engine speed and therefore generate noise or cause engine running problems.

The requirement of leakage rates less than the gasoline discharge rate required for having the engine idle involves the setting of limiting values for D_1 and D_2. In reality, the experiments made with solenoid valve prototypes according to the invention show that even when the leakage rate

is larger than these limiting values, operation is satisfactory. This is then a so-called mixed mode operation, where both curves are such that $I_s < I_2$, which means that linear operation of discharge rate control occurs before the rated operating pressure value has been reached in the rail (4).

It should be noted that, considering the invention-specific design, such operation may be managed as the leakage rate amount exceeding the threshold values D_1 and D_2 may be recycled by the flap device, by means of information provided to the electronic central unit by the pressure sensor.

The configuration shown above of course is only a possible example of the invention, which is by no means exhaustive. Any change in the form and configuration which is within the competence of one skilled in the art lies in the scope of the present invention.